Report of the Mars Environmental GIS Workshop

Workshop held October 5-6, 2005, SETI Offices, Mountain View, CA

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Workshop Desired Outcomes

1. An assessment of the potential for a Mars environmental interpretive and query capability using GIS to provide an environmental classification of different sites on Mars with respect to both planetary protection concerns and science opportunities.

2. A description of the characteristics a Mars environmental GIS would need in order to achieve that potential and to optimize its utility.

3. A development plan describing the work needed to achieve the envisioned future state, including priorities and budget.

Summary Conclusions (1 of 3)

1. It is possible to establish a system that would classify martian environments by their biological potential and that could display these interpretive classifications in map form. This interpretive approach would be useful for both planetary protection and science applications. Some specific considerations:

   a) It is possible to identify a number of mappable parameters that relate to the potential for different martian environments to constitute habitable niches for exogenous Earth-sourced microbes.

   b) Interpreting habitability potential is subject to the following:

      - Interpretation of the biological impact of spacecraft operations on Mars will need to incorporate not just martian data sets, but also Earth-based laboratory data, terrestrial analog studies, survivability analyses, biotoxicity studies, and other types of information
      - Interpretations of progressively higher quality will be possible as more and more data are brought to bear. We currently have no way of setting a threshold for 'enough' data.

   c) To interpret habitability potential for possible indigenous martian life forms, we have no practical alternative but to start from our understanding of life as we know it. Thus, indigenous habitability parameters, to first order, are the same as those in #1a above.

   d) It is possible to map areas with definite geological and environmental meanings, and these could later on be interpreted as "special" or "not special". However, it is not presently possible to map a boundary between "special regions" and "non-special regions" because the term 'special' is not well enough defined.

Summary Conclusions (2 of 3)

2. The environmental classifications could be best integrated via a Geographic Information System, or GIS—in fact, the workshop concluded that this is probably the ONLY way to achieve a credible result.

3. Drawing spatially resolved habitability interpretations is but one application of a broad-based martian GIS.

   a) Several prototype GISs have been developed for Mars, three of which were demonstrated at the workshop. They illustrate both the potential value and some of the challenge areas of setting up a system of global scope.

   b) There are key lessons to be learned from GIS experience on mapping spatial data on Earth. These also illustrate some of the potential and some of the challenge areas.

   c) Planetary protection decision making is one potential use of a full martian GIS, and support for developing this aspect of GIS capabilities will contribute to establishing broad program-level capability.

Summary Conclusions (3 of 3)

4. Key improvements for existing martian GISs would enhance usability and effectiveness, such as:

   a) Enhanced data standards

   b) Better organization and leadership

   c) Additional secondary data products in PDS

   d) More precise geodetic control [At present, Mars spatial data sets are difficult to co-register given data resolutions that in many cases exceed the capability of established geodetic controls and given uncertainties in spacecraft instrument location and pointing geometries.]

   e) Better understanding of funding sources.

Recommendations (1 of 2)

1. We recommend that the ‘environment’ for GIS growth be created with the following initial steps:

   a) We recommend that a panel be chartered to develop data standards and the processes necessary to allow data to flow into GIS-usable databases. This recommendation applies to the entire Mars program (and at an international level), not just to the MEGIS application.

      - Composition. approximately 8-10 people. At least one representative from HQ. 1-2 folks from PDS. 1-2 foreign participants.
      - Leadership. Co-leaders: somebody who is an expert in databases and application software, and a Mars scientist. Strategy—give them some organization and lots of rope, and see what develops.
      - Timing. Produce recommendations by May, 2006? This would allow the option to influence NASA's FY07 budget.
      - Reporting. Initial reporting to the Mars Program Office, who will also be responsible for providing funding for panel expenses (esp. travel).
      - Review. Recommendations need to go through a peer review process.

   b) International cooperation will be needed, including data contributions from multiple missions (e.g., MOC, MOLA, GRS, THEMIS, OMEGA, HRSC, MECA, etc.), and agreement on data standards and formats.

Recommendations (2 of 2)

2. We recommend creation of a Mars environmental interpretive capability, enabled by Mars GIS growth, that could credibly be used for planetary protection decision-making.

   a) Activities in progress that need to continue to generate inputs to such a system:

   - The collection and interpretation of data of relevance to habitability, including the distribution of water (present/past/future, ices, salinity etc), oxidants/reductants, methane, T/P, UV frequency and intensity, dusts etc. Many of these data sets are actively being generated by instruments on spacecraft currently in service at Mars. **ACTION: Mars flight missions.**
   - Simulation studies to determine the conditions of survivability of terrestrial microorganisms found on spacecraft , using both Mars simulation laboratories, and studies of terrestrial analogs. **ACTION: Increased support by NASA R&A programs, possible directed support by Mars Program.**
   - Integration of all the above into habitability models that combine the disparate information types into an overall interpretation of habitability potential. **ACTION: form a PP/astrobiology panel—needs more discussion on specifics.**
   - Continued improvement of Mars environmental GIS prototypes. **ACTION: Provide financial support by the Mars Program or the NASA PPO.**

   b) New activities needed:

   - Produce a comprehensive inventory of organisms typically sent to Mars on out-bound spacecraft. **ACTION: Provide financial support by the Mars Program.**
   - Develop a system for validating the inputs and algorithms used in reaching these interpretations would need to be established. **ACTION: Requirements to be considered by PP/astrobiology panel.**

Why GIS for Mars Planetary Protection?

- Identification and mapping of regions of habitability (special regions) will require correlation between many data sets of different types which is enabled by GIS.
- Large data volumes being accumulated from Mars are transforming our understanding of the Mars environment and **will require** a management tool like GIS, particularly if correlation needs to be done on a global scale
  - Viking
  - Mars Global Surveyor
  - Mars Odyssey
  - Mars Express
  - Mars Reconnaissance Orbiter

  And future missions..
- Capability to zoom between very wide geographical regions (eg. 1000km) and very localised (eg. sub-cm) ones will aid use of both lander and orbiter data
- Once the characteristics of special regions are better refined and understood the analytical capabilities enabled by GIS will be required operationally for future robotic and human missions.
- This GIS would enable the informed public (lay-person) to have greater access to the information regarding planetary protection decisions. This can have a powerful effect in demystifying the process.

Summary of Breakout Group Findings/Reports

Group #1: Habitability
Group #2: GIS/IT considerations

Habitability-Survivability – Forward contamination problem

- Primary Assumption: Address life as we know it – carbon & water-based Life
- Planetary Protection should focus on microbial bioloads expected on Mars-destination spacecraft
  - Survivability of these organisms can be addressed by consideration of the martian data, earth-based experiments and other data derived from ecological studies in simulated environments
- Mars Datasets that are important to understanding habitability-survivability issues :
  - Geology
    - Imagery (MOC, Viking, HRSC, THEMIS, HIRISE)
    - Mineralogy – THEMIS, TES, OMEGA, CRISM, etc.
    - Elemental, isotopes, etc.
    - Topography
      - MOLA
      - Stereo photogrammetry
        - HRSC, HIRISE, etc.
    - Subsurface
      - MARSIS, SHARAD, GRS,
      - Gravity, magnetics
    - Lander Data
    - Meteorites
  - Atmosphere
    - PFS, MCS, TES
    - Temperature, pressure
    - Composition, isotopes
    - Radiation, weather
    - Methane
    - Ground based data (telescopic, radar)

Report from Break-out Group #1: Habitability Parameters

Constraints for Habitability-Survivability (1 of 2)

Note: These constraints are required in diverse combinations of synergistic factors in order to permit active metabolism, replication, and adaptation of terrestrial life to Martian conditions.

- Water inventories
  - Presence of liquid
  - Past/future liquid (ice) inventories
  - Conducive ranges of salinity, pH, and Eh of stable liquid water on Mars
- Chemical requirements
  - Nutrients
    - C,H,N,O,P,S, essential metals, essential micronutrients
    - Fixed Nitrogen is the biggest unknown
    - Availability/Mineralogy
  - Toxins
    - Abundances
      - Heavy metals (e.g., Zn, Ni, Cu, Cr, Ar, Cd, etc.) [some essential metals are toxic at high levels]
      - Oxidants (What species of oxidants exist and how stable are they at the surface?)
  - Lethality [What are the inhibitory versus biocidal levels of toxins, heavy metals, oxidants, etc. on spacecraft microbial communities on Mars?]
- Energy for Metabolism
  - Solar [surface and near-surface only]
  - Geochemical (redox couples) [subsurface]
    - Oxidants
    - Reductants
    - Redox gradients

Constraints for Habitability-Survivability (2 of 2)

- Conducive ranges of Physical Processes and Conditions on Mars
  - Temperature [What are the temperature minima for spacecraft contaminants?]
  - Pressure [There may be a low-pressure threshold for terrestrial microbes.]
  - Geothermal [Can spacecraft microbes access geothermal sources?]
  - Radiation (UV, ionizing) [Radiation sources will impact survival and growth.]
  - Climate (geography, seasons, diurnal, obliquity variations) [Pertains to long-term adaptation to Martian conditions.]
  - Substrate (soil processes, rock microenvironments, dust composition, shielding) [The effects of Martian edaphic factors on microbial survival, growth, and adaptation are not understood.]
  - Stability of these parameters over time.
  - Transport (aeolian, ground water flow, surface water, glacial)
  - Periglacial, lacustrine, aeolian processes also must be studied relative to the habitability of Martian locations to terrestrial life.

Report from Break-out Group #1: Habitability Parameters

Links between Habitability/Survivability constraints and Martian datasets (1 of 3)

- Water (present, past, future liquid (ice), salinity, pH, Eh)
  - Odyssey Gamma-Ray Spectrometer (GRS) data (hydrogen and salts)
  - Phoenix wet chemistry and other lander data
  - Ground penetrating radar (SHARAD, MARSIS)
  - Atmospheric water and methane from orbital, telescopic, and ground-based
  - Mineralogical and compositional data (MGS, Odyssey, MRO, Mars Express)
  - Geomorphology (Viking, MGS, GRS, MRO, Mars Express)
- Fixed Nitrogen
  - Extrapolating from meteorites combined with Orbital Data
  - Phoenix data?
- Toxic metals
  - GRS, MER (APXS), martian meteorites
- Oxidants
  - Phoenix (MECA), Viking biology experiments
  - Martian simulations (? – How to extrapolate to global)
  - Global mineral maps
  - Mars Express (SPICAM – atmospheric oxidants)
  - MSL

Links between Habitability/Survivability constraints and Martian datasets (2 of 3)

- Reductants/ Redox gradients
  - Global mineral maps
  - Methane (PFS, telescopic measurements)
  - Indicators of Crustal convective processes (e.g., hydrothermal) – THEMIS?
  - Heat flow – THEMIS
- Temperature, pressure (largely done for surface environment)
  - MRO, Viking
  - Lab experiments for microbial survival
  - Time variations, diurnal, seasonal, climate
- UV
  - Theoretical models seem well established
  - No in-situ measurements on the surface (SPICAM?) [Definitely required.]

Links between Habitability/Survivability constraints and Martian datasets (3 of 3)

- Lander Data are required to extrapolate localized geochemical regolith data to global mapping GIS efforts.
- Microbial survivability studies under Martian conditions (i.e., via Mars simulations) are essential for constraining the limits of growth of terrestrial microorganisms found on spacecraft on Mars.
- Mars analog soil studies are required to better predict compositions, chemistries, and mineralogies of Martian regolith. In addition, high-fidelity Mars analog soils are required for robust microbial survivability studies.
- Martian meteorites offer a wide range of data that can be applied to characterizing the survivability of terrestrial microorganisms to Martian conditions.

Technical Coordination

- Designate group or committee as contact for coordination and outreach related to data standards
- Group would work with planetary programs, mission planners, and data archivers, such as:
  - NASA HQ and Centers
  - the Planetary Data System (PDS)
  - Universities
  - Other research facilities (e.g. SETI, USGS, Smithsonian, etc.)
  - Foreign Partners (e.g. European, Canadian, Japan, Indian)
- Group would seek funding partners with similar goals with PP

Geodetic (Areodetic?) Control

- Require community-accepted standard for geodetic control (e.g., Mars datums) for consistent datasets co-locating
- Need tools that will implement the transformations for different user communities
- Need to expand Earth-based data format standards to accept parameters for planetary projections
- Need to coordinate with GIS analysis software vendors (e.g., Leica Geosystems, ESRI, RSI) to get these standards implemented

Report from Break-out Group #2: IT Considerations

Promote Dataset Synergy (aka PDS)

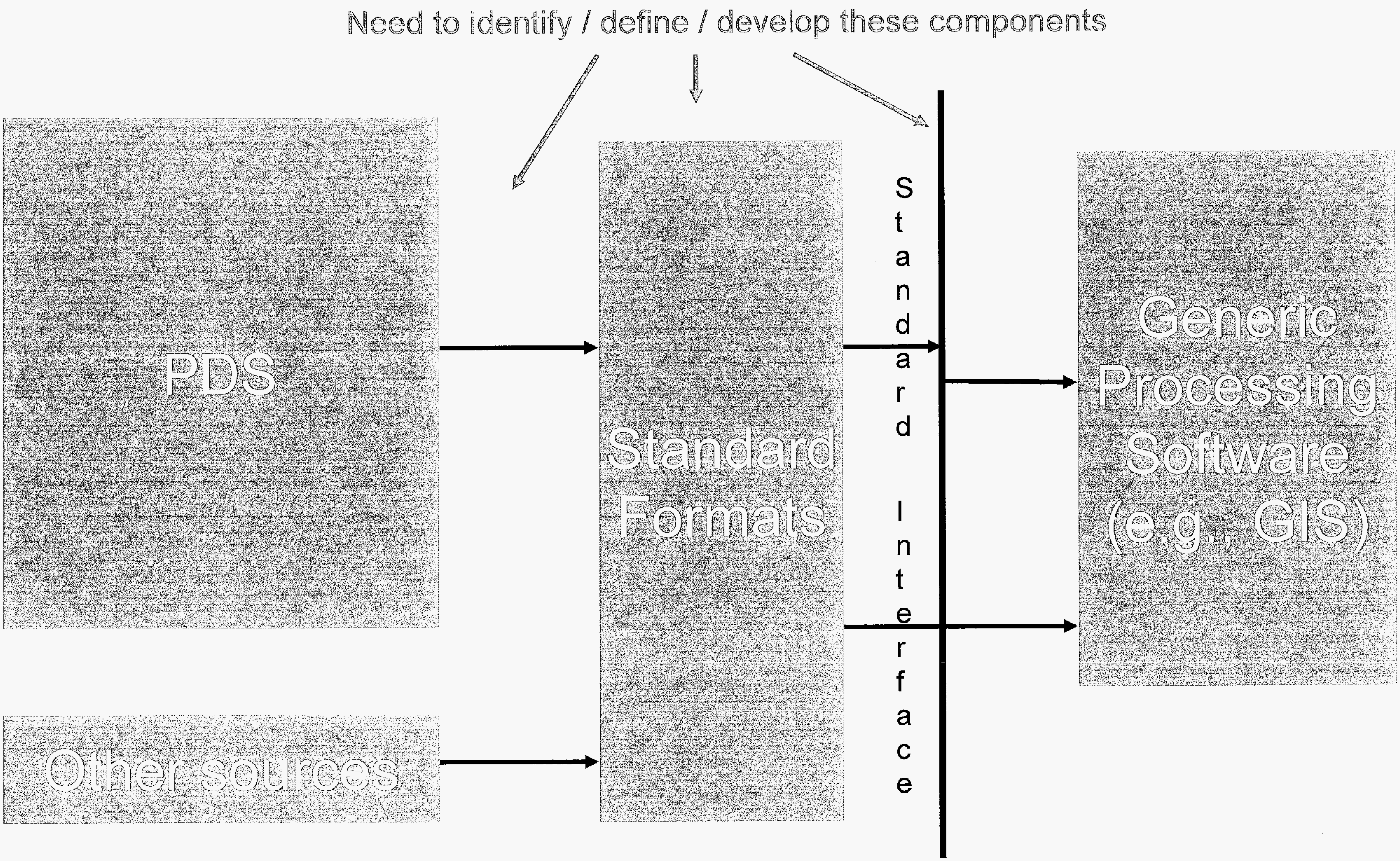
- "GIS-ready" data that are easily used by researchers for display and analysis via Planetary Data Systems (PDS) or other
- Better defined processing steps for commonly used/requested data sets
- Easier tools/capabilities for processing raw data from each instrument into standard format(s)
- Provide validated/calibrated data in both raw and map projected formats
- Need improved data catalog / discovery capability whether the datasets reside at a centralized entity or individual research facility

Software

- Need better GIS capabilities for temporal data sets, parameters, or both
- Define processing and/or functionality gaps for PP
- Cross-platform GIS software (e.g., Windows, Mac, Linux) that can be freely distributed

Report from Break-out Group #2: IT Considerations

System Architecture



GIS Recommendations

- Form a "tiger team" to evaluate GIS issues and options
- Clarify PP data gaps, analysis, and modeling requirements
- Produce data (types, format, and interface) and analysis specifications (including time-series data) for a prototype PP MEGIS and build it
- Facilitate putting datasets judged to be important into GIS
- Provide researcher and public access through web services, e.g., web map server (WMS) and web coverage server (WCS)

GIS Recommendations (cont)

- Provide "on-line services" to help process datasets that are not easily derived as a single final product (e.g., MOC narrow angle, THEMIS visible images).
- Work with future mission planners to "task" instruments and define processing steps to meet geodetic standards
- Develop outreach activities to educate the planetary community about the benefits of:
  - GIS software for spatial analyses
  - Community-supported data formats

Highlights from workshop presentations

History of Recommended Pg Values
(probability of growth)

PP Policies Revised Over Time

(Changes reflect understanding about Environment and Microbes at the time)

If P_g= 0, then no PP controls (regulations)

If P_g = 1 then very strict

If Uncertain?

'60-'80s: Probability of Growth P_g Assigned

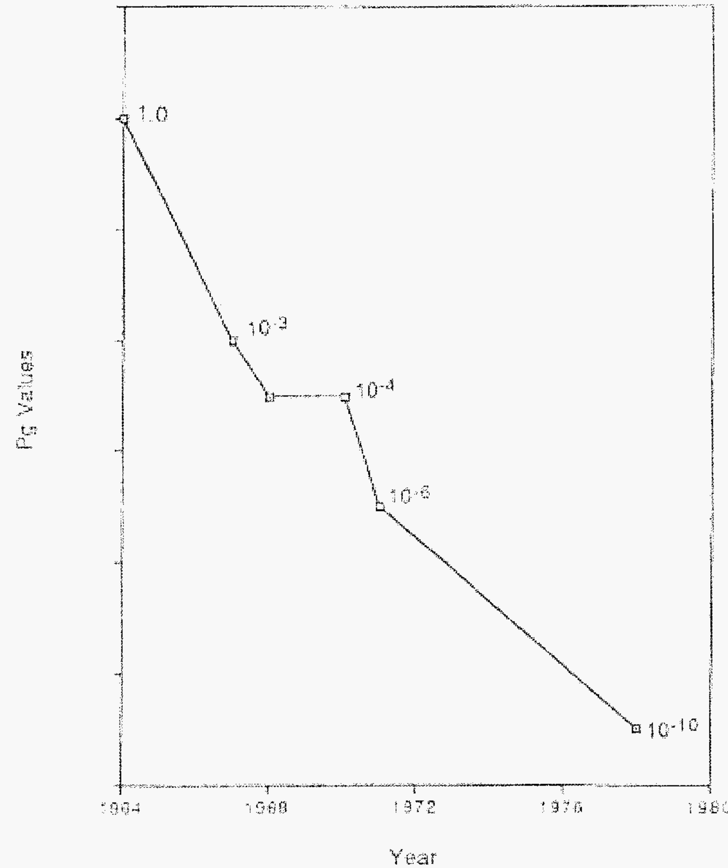
1982:   Adopted Categorical Approach

1992: NRC P_g presumed to be near zero for Earth microbes

2005 PREVCOM: Likely increases in P_g

✓ Greater potential for liquid water on Mars

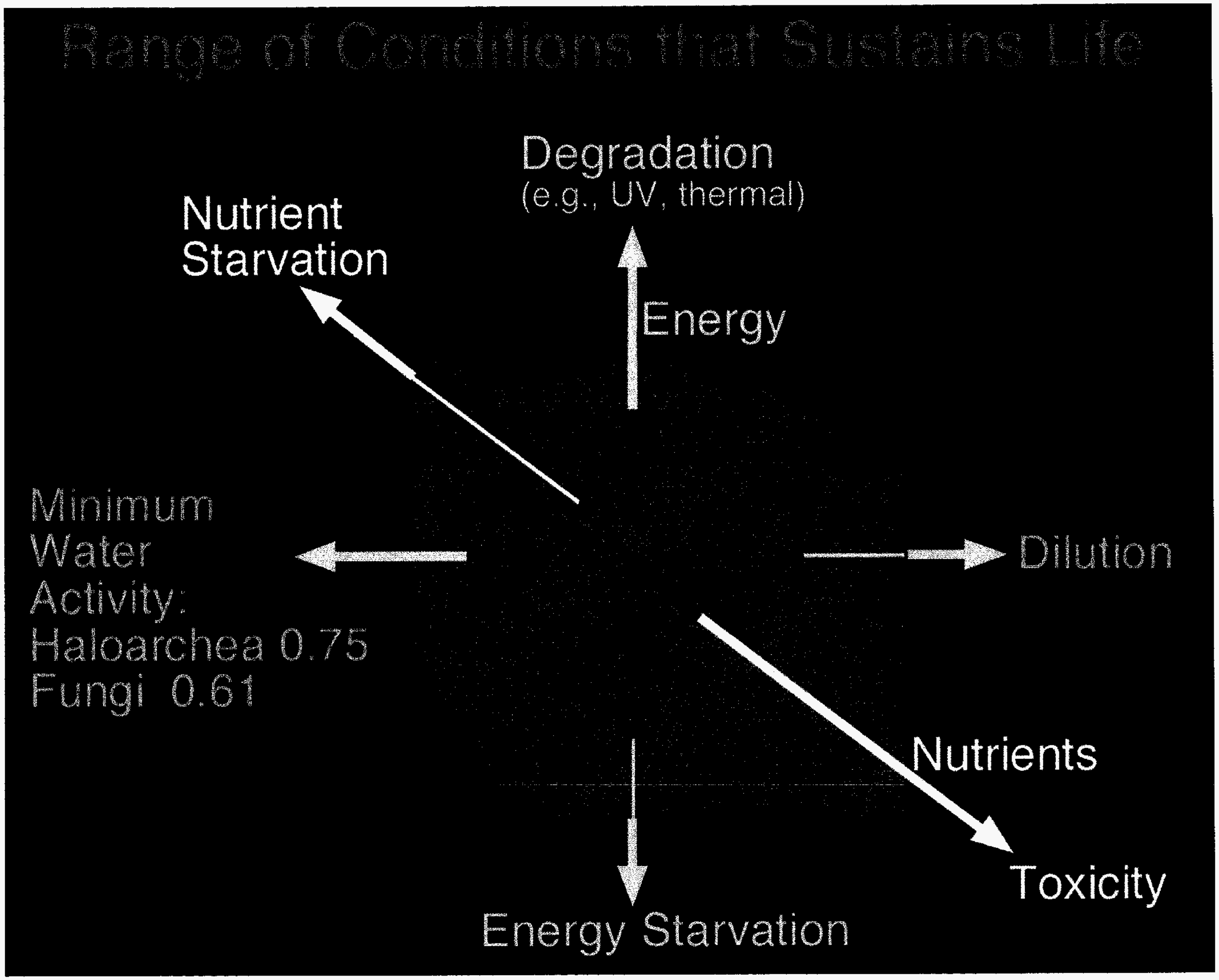
✓ Knowledge about extremophiles/microbes



SOURCE: H.P. Klein, 1992.
History of Pg, in H.P. Klein, ed., Planetary Protection Issues for the MESUR Mission: Probability of Growth (Pg), NASA CP 3167, pp. 41-52.

Content source: Margaret Race, SETI

Range of Conditions that Sustains Life



When and where did (does) this set of conditions exist on Mars?

Content source: David Des Marais, ARC

Assessment of Biological Potential for Martian Life

Water

1. Partitioning of elements
2. pp of atmospheric gases
3. Temperature
4. Available light
5. Other energy sources
6. Electrical/magnetic environment
7. Other ionizing radiation

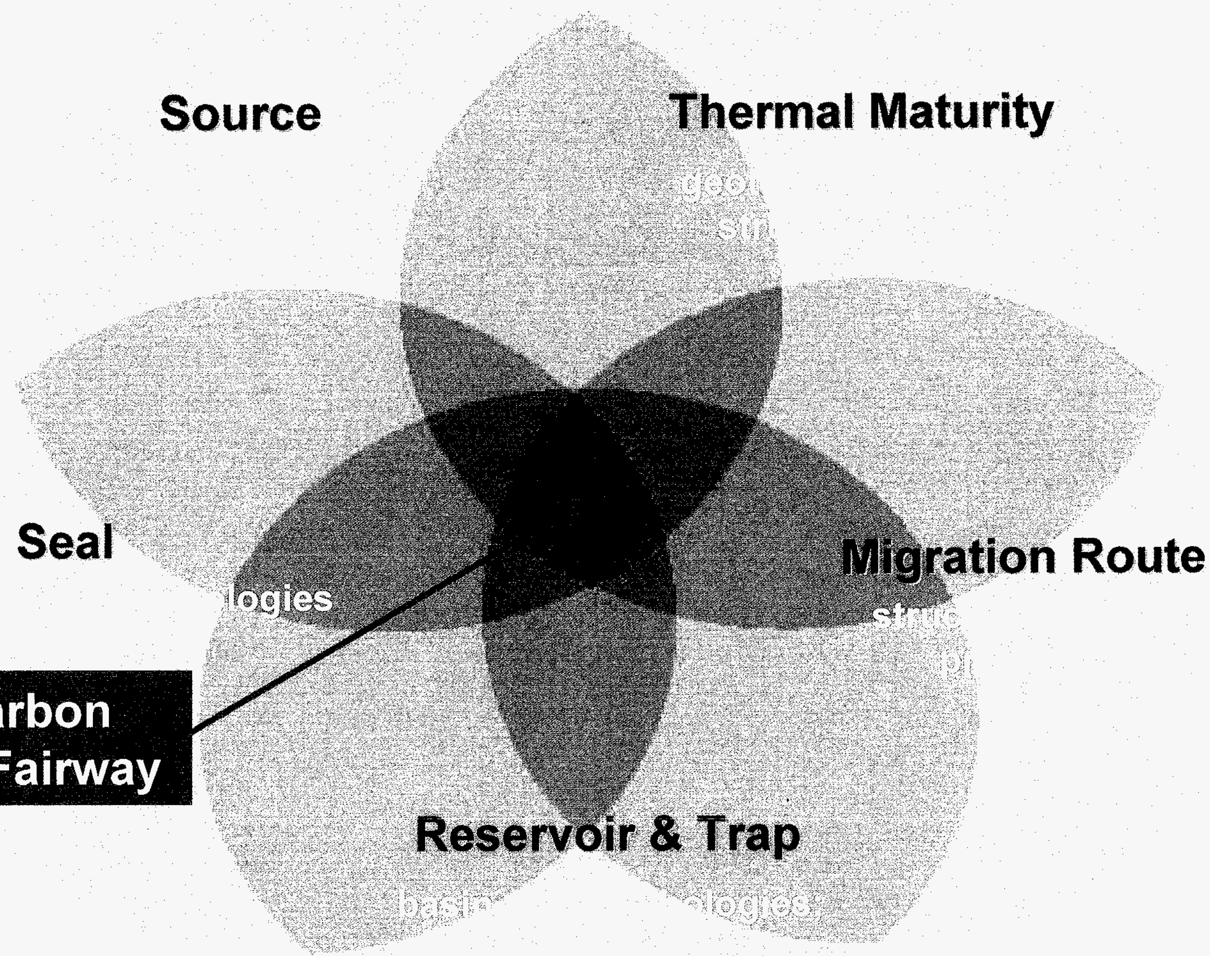
1. Geomorphology
2. Rock type
3. Mineralogy
4. Geochemistry
5. Sedimentary structures
6. Stratigraphy
7. Geographic context

Organic Molecules

Content source: Pan Conrad, JPL

Terrestrial Example: Prospecting for Oil and Gas

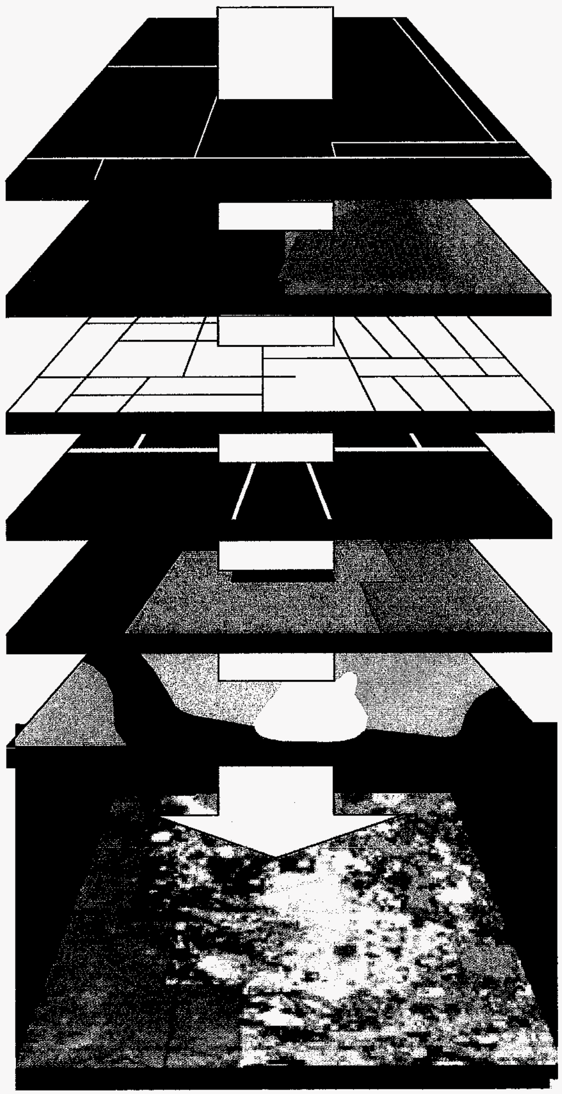
Intersection of Critical Parameters



Area of Hydrocarbon Accumulation = Fairway

Content source: Dorothy Oehler, JSC

GIS Integrates the Parts



Mineral

Geology

Structure

Nomenclature

Topography
Satellite Imagery

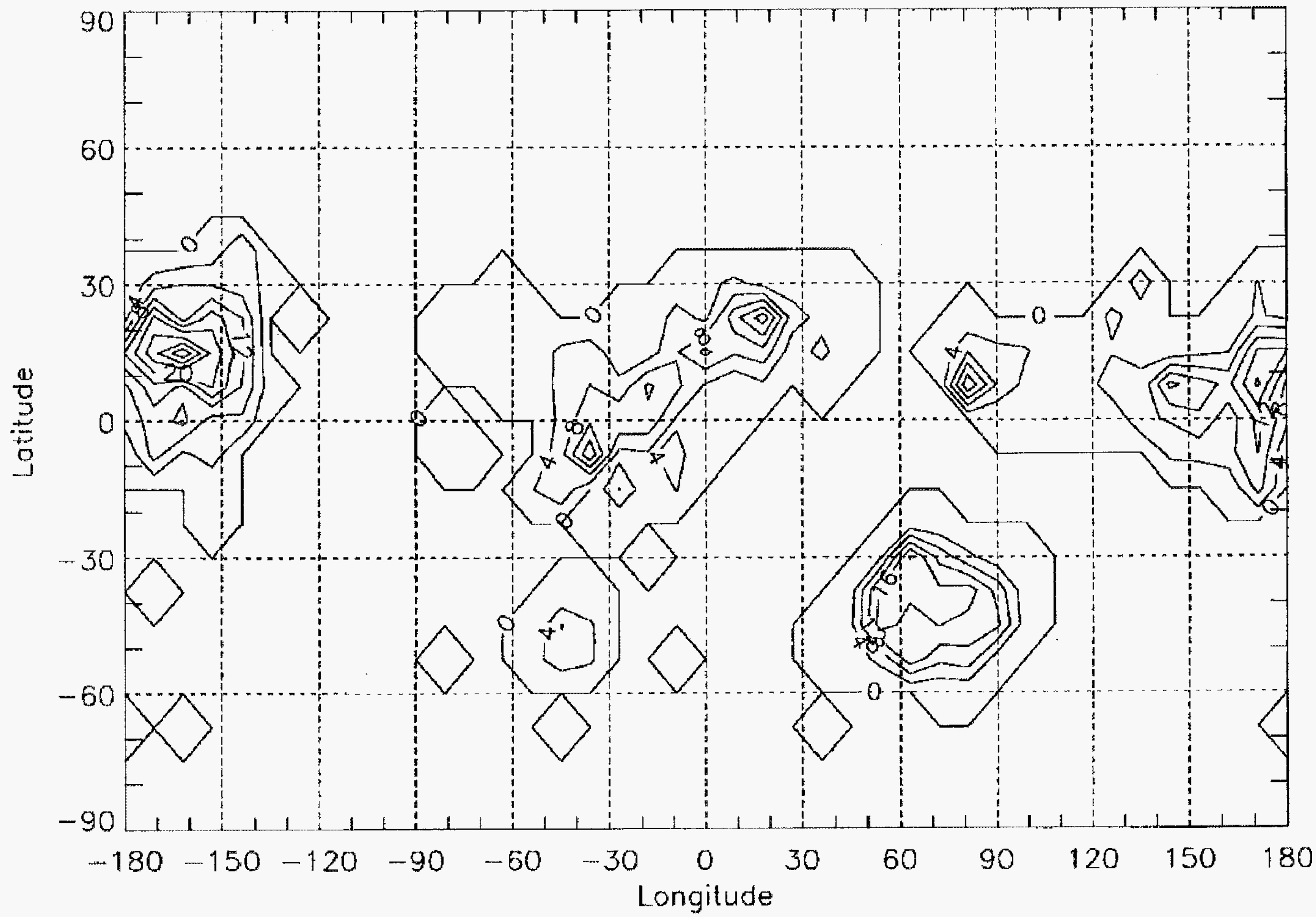
GIS is a visual language

Special Regions and GIS

- We don't know where the special regions are on Mars (if any), but we have a long list of potential suspects
- NASA needs to devote greater effort to making measurements relevant to determining the extent(s) and properties of potentially special regions
- The datasets and models we currently have provide information on very large (km) scales (Odyssey GRS, thermal, GCM's), but the most special regions may be highly localized (slopes, inside or under rocks, hot spots associated with recent volcanism). The notion of a contiguous special region may be an oversimplification
- GIS has the potential to span great resolution scales, but the input data and models must provide the necessary relevant information at the relevant spatial scales for the analysis to be worthwhile
- GIS systems are often designed for non-experts, but identifying special regions on Mars is definitely a job for experts....

Content source: David Paige, UCLA

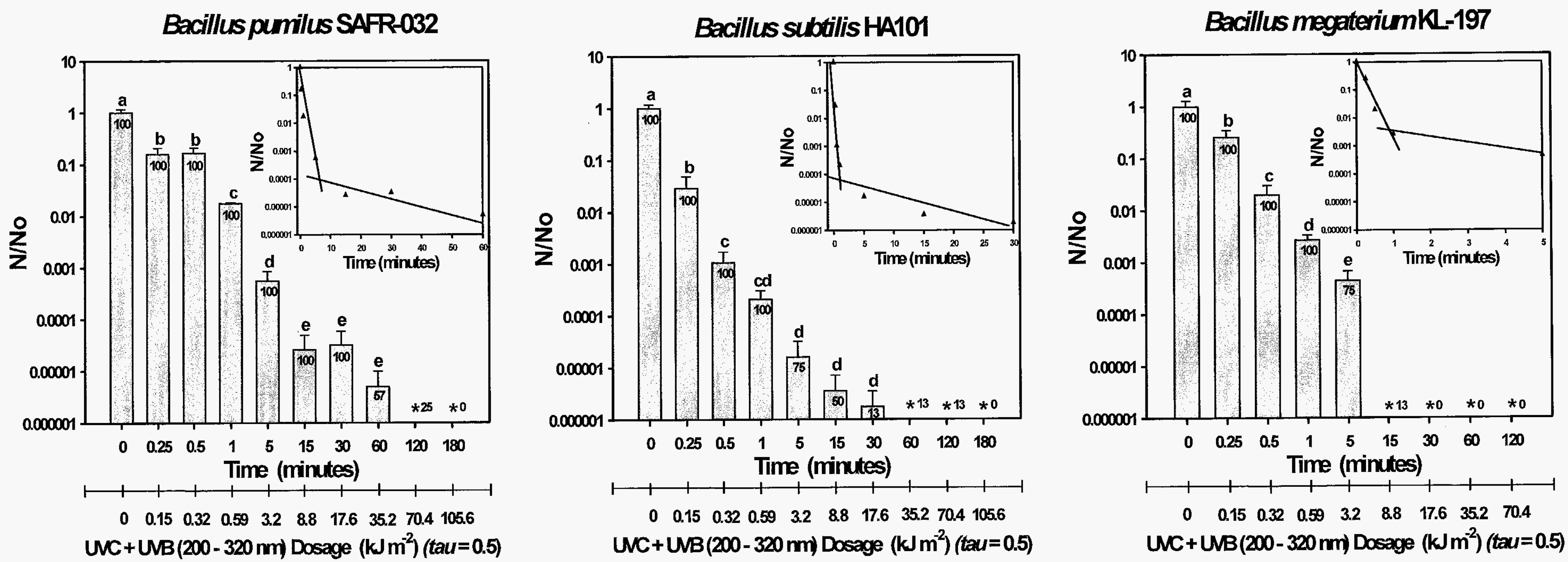
Current Liquid Water Stability



Contours show the number of Mars sols per Mars year where GCM calculations predict conditions permitting the current transient stability of liquid water on the Martian surface (Haberle et. al., 2001)

Content source: David Paige, UCLA

Effects of UV dosage on the Survival of Bacillus subtilis HA101 under Mars-Normal UV and Earth-Normal Environmental Conditions.



Rapid inactivation kinetics under equatorial Mars UV simulations.

Content source: Andy Schuerger, Univ. Florida

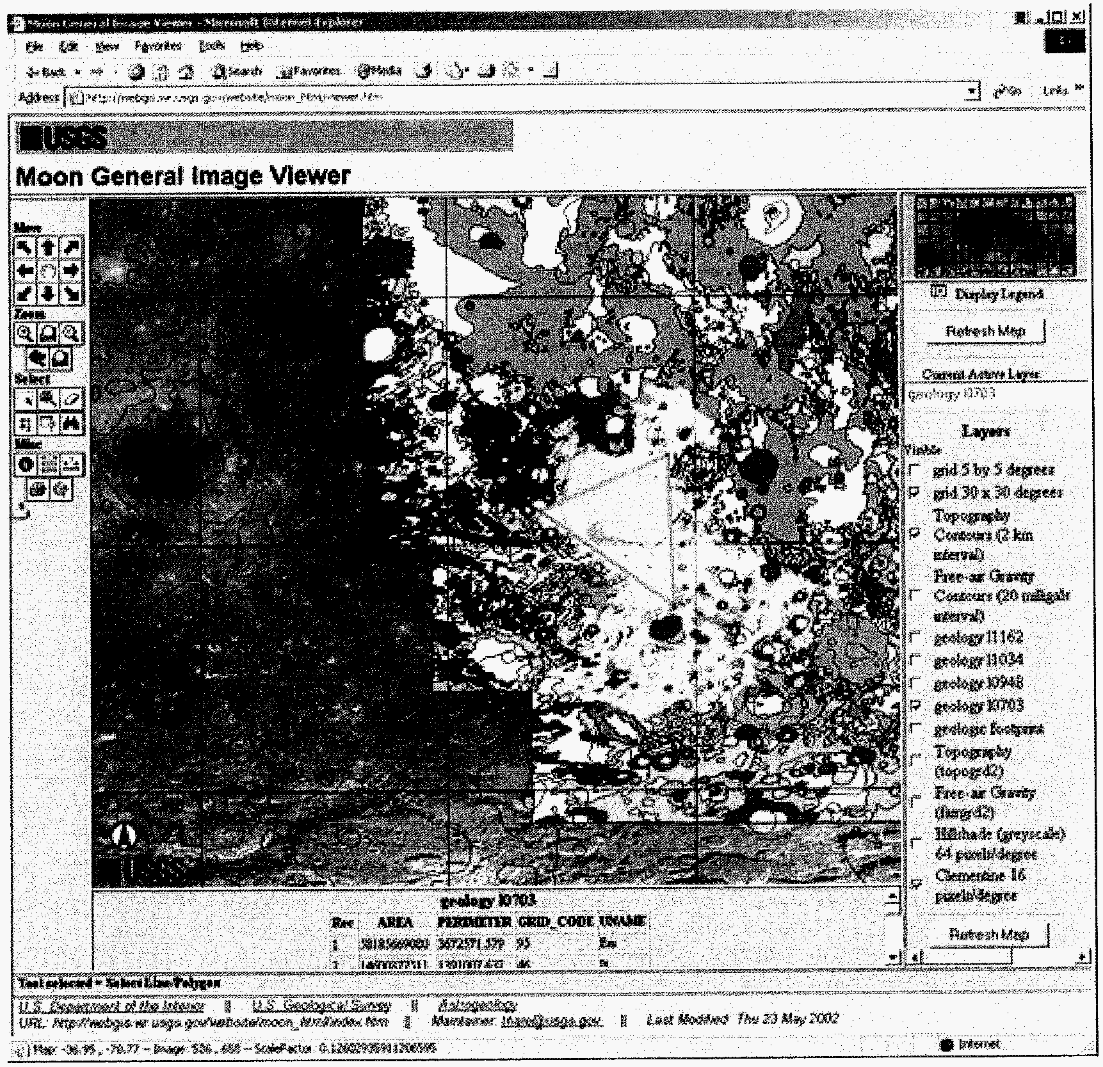
PIGWAD (GIS Server) - Bodies On-line

- Mars
  - General image bases
  - Geologic maps
  - Crater catalogs
- Venus
- The Moon

Galilean Satellites

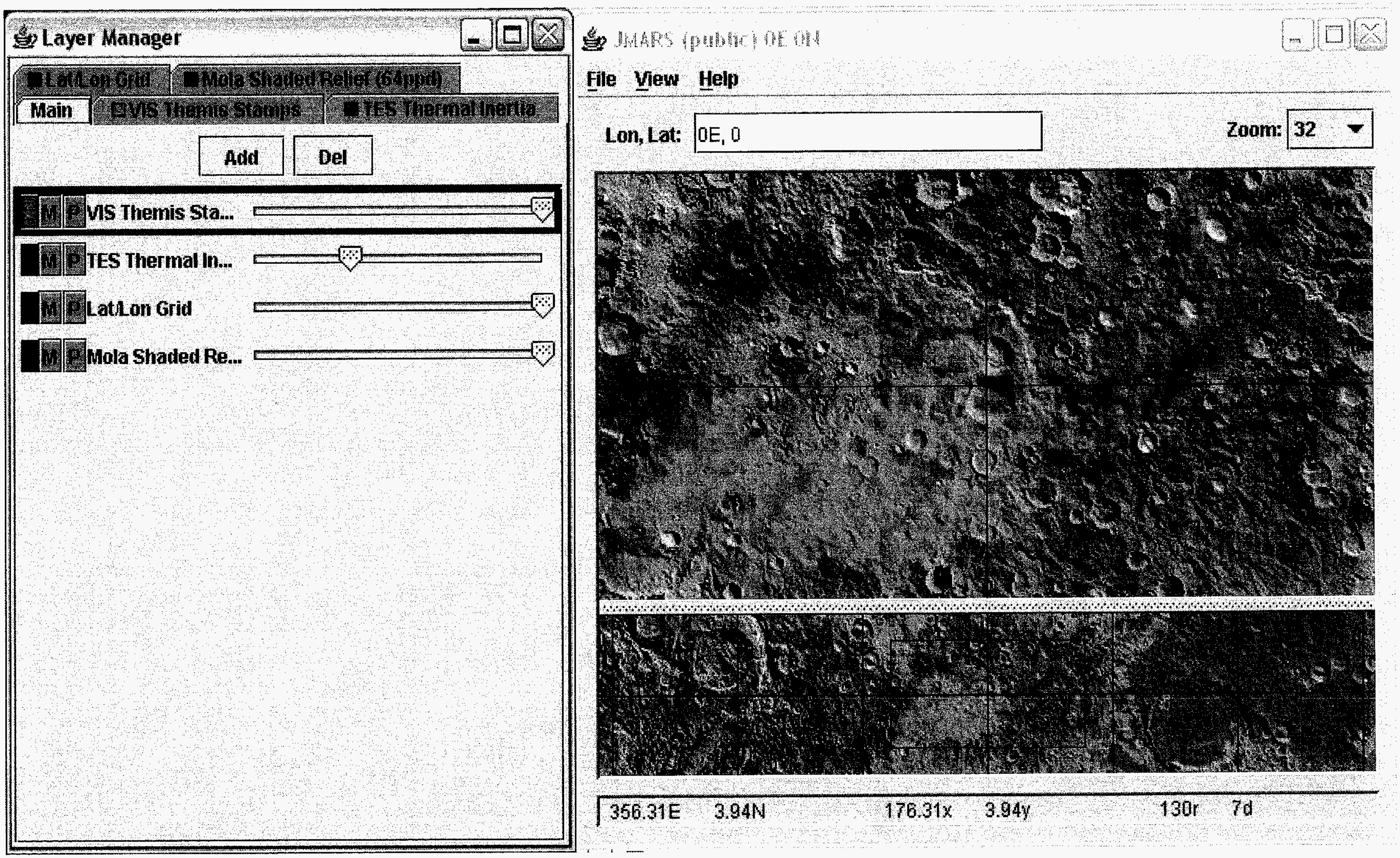
- Callisto
- Europa
- Io
- Ganymede

- Titan (mission support)



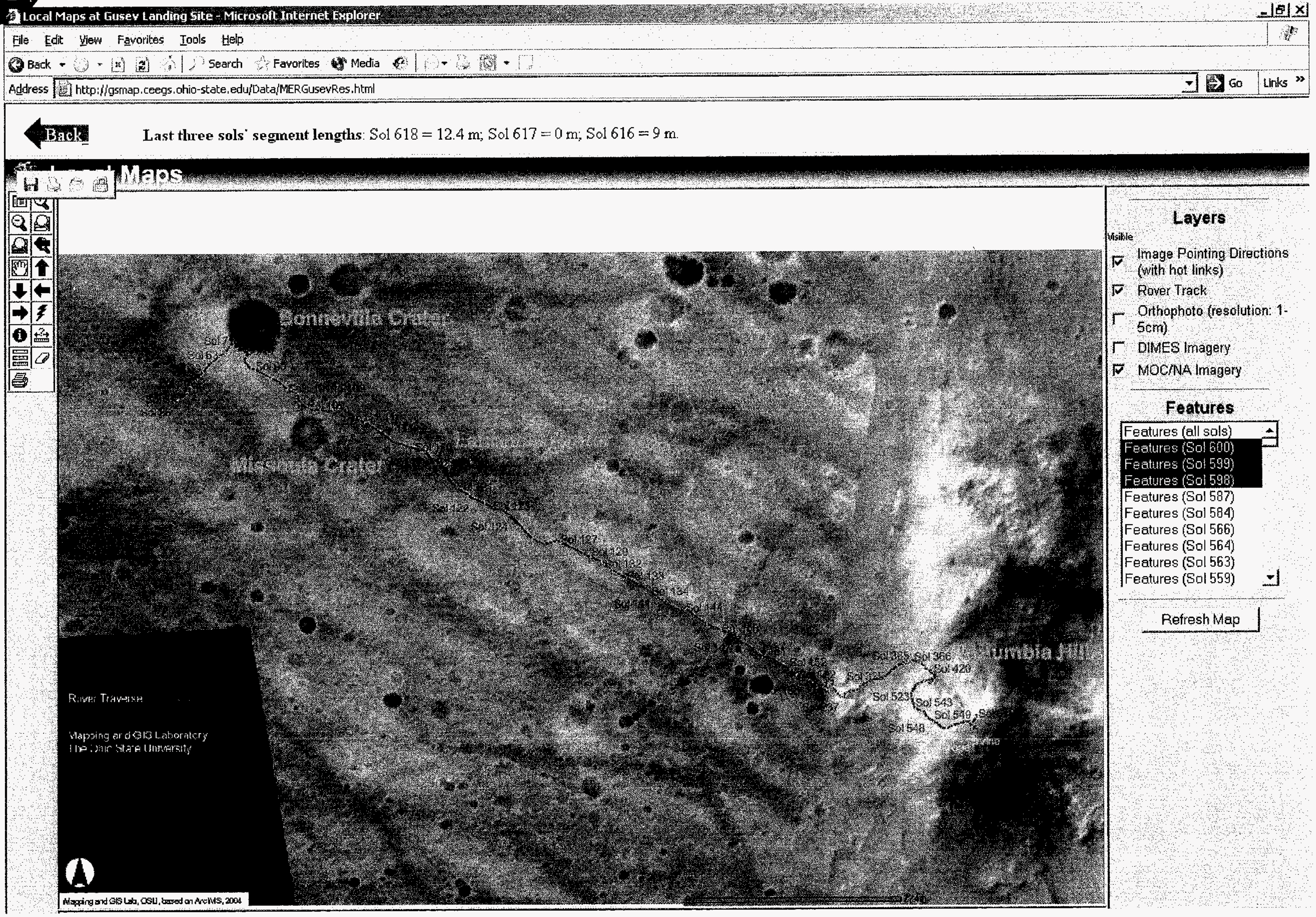
Content source: Trent Hare, USGS

JMARS (Mars Odyssey THEMIS Mission Planner)



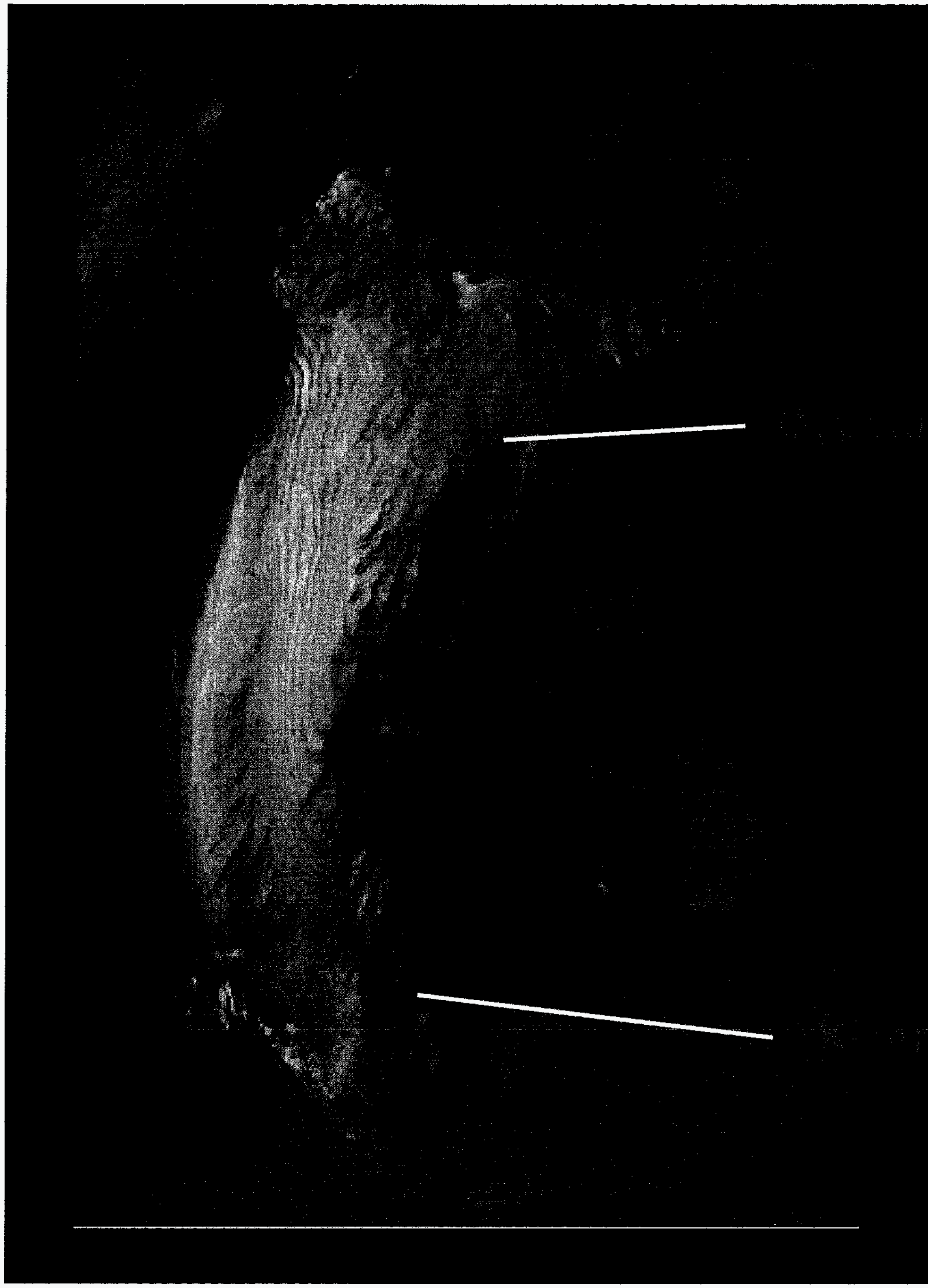
Content source: Trent Hare, USGS

OSU MarsMapper/GIS



Content source: Ron Li, Ohio State Univ.

Example GIS: MEX



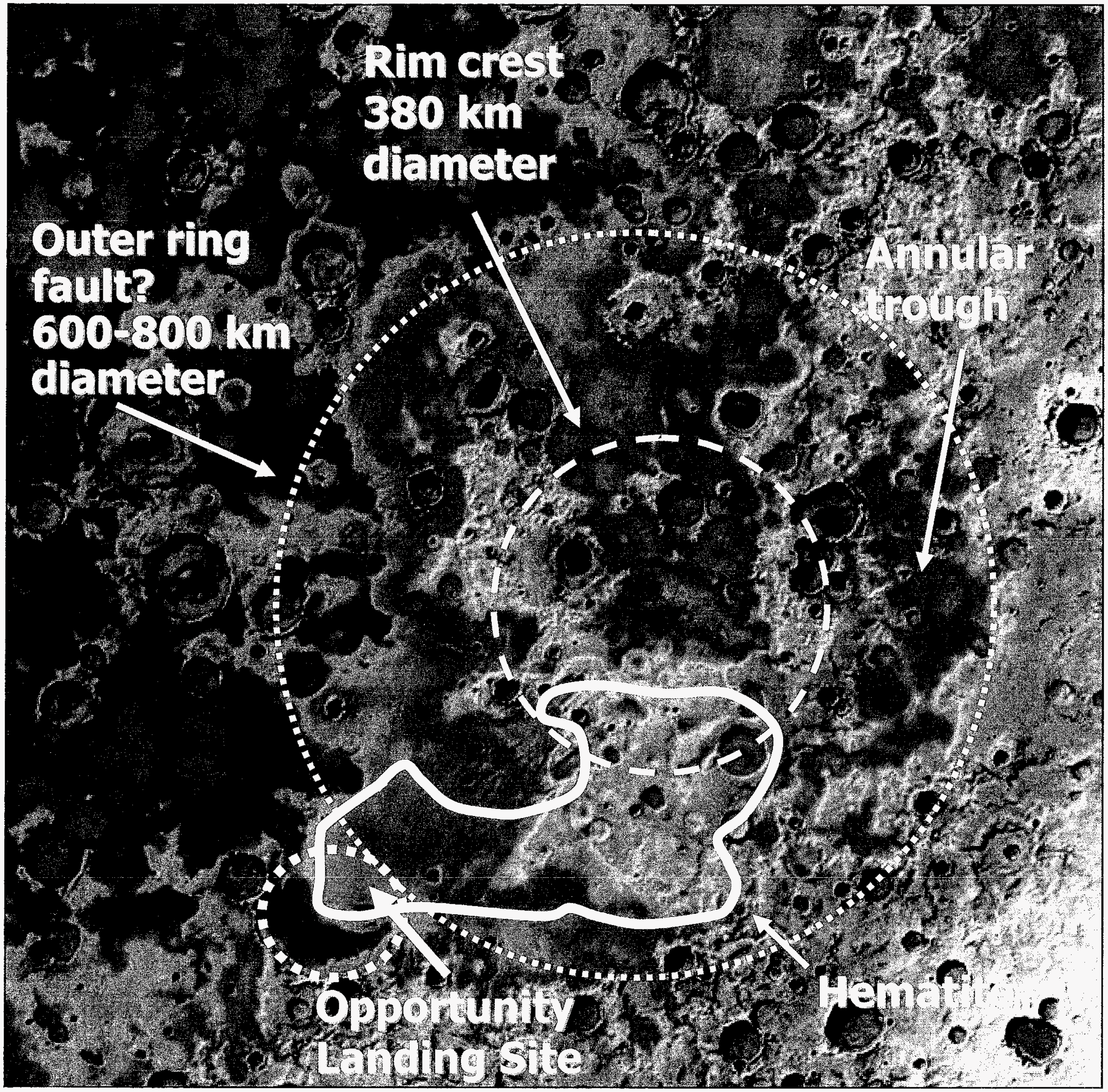
Omega data over HRSC images

Evaporitic deposits in Juventae Chasma

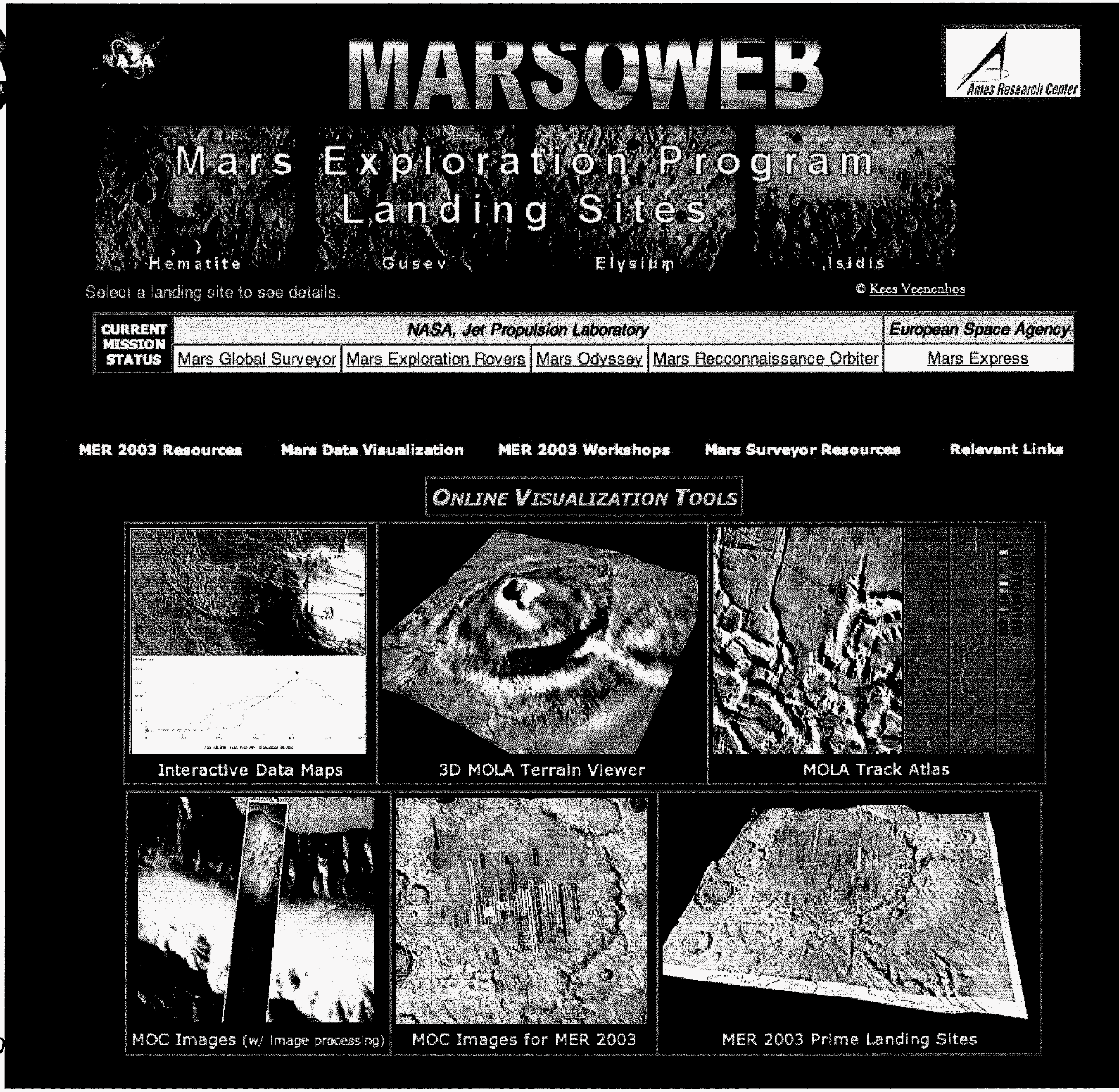
Content source: Gian Ori, European Space Agency

Example: MER landing site selection activity (Newsom et al., 2003) Marsoweb and GIS used to examine topography

Multi-ringed basin may be responsible for localizing channels and sedimentation in Meridiani



Content source: Horton Newsom, Univ. of New Mexico



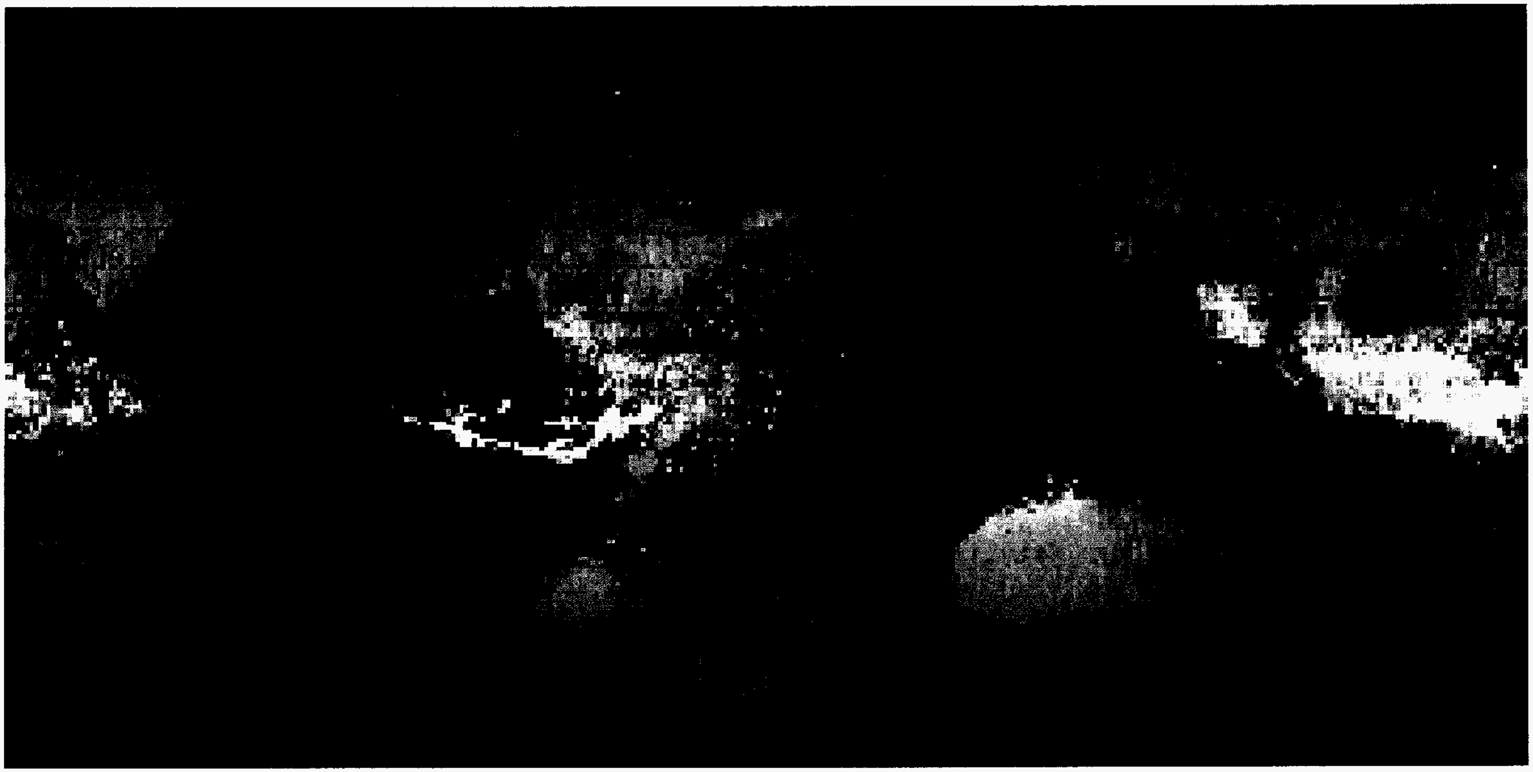
Content source: Ginny Gulick, NASA Ames/SETI Institute

Marsoweb's Interactive Visualization & Analysis Environment for Mars Studies

- Marsoweb (http://marsoweb.nas.nasa.gov) was developed for the Mars science community and the MEP personnel to support and facilitate the MER landing site studies and selection effort. It uses JAVA technology incorporating various applets that operate within the user's browser environment.
- All landing site meeting presentations, abstracts, and memoranda on the MER landing sites are archived on Marsoweb.
- All scientific & engineering data used by the community for landing site selection studies were incorporated into interactive data maps overlain on a base map of Mars. Actual data values are queried by moving the cursor over the data map. All candidate sites proposed are archived with a variety of maps and interactive 3D perspective views of the landing sites.
- Interactive data maps currently available on Marsoweb: MOLA, geology, TES Thermal Inertia & mineralogy, bulk thermal inertia, fine component inertia, rock abundance, vertical roughness, MOC image footprints and THEMIS (vis & IR) image footprints with hyperlinks to actual images.
- Marsoweb tools currently provide online image processing tools (e.g. lighten, darken, sharpen, smooth, zoom in/out, equalize, adjust histogram brightness and contrast levels), interactive MOLA orbit track locator and profile generator, 3D MOLA interactive terrain viewer, an interactive cross-section profile generator of MOLA topographic data and other global data.
- We are also developing HiWeb (based on Marsoweb) for MRO-HiRISE and will provide an interactive HiRISE image suggestion facility and HiRISE image viewer and analysis environment in context with other available Mars data.
- Marsoweb has plans to support the MSL landing site studies and selection effort with further tool development.

Example Environmental GIS: Time Series Suitability Result

(-180,90) (179.5,90)



(-180,-89.5) (179.5,-89.5)

Key

Raster layer: Query result (units: percent)

2.778 94.444

Gully locations
All values

Grayscale result representing the percent of the martian orbit where the specified conditions were determined to be true. The conditions were: surface temperature (measured by TES) > 273K and pressure (calculated from MOLA altitude and seasonal variation) > 6.1mb. In blue are a set of gully locations identified by Jennifer Heldmann (personal communication).

Content source: Lobitz and McKay, ARC

MEGIS output

The importance of validating a "special region"

- Regulatory approach (eg. EPA)
  - Regulatory body sets quantitative requirements for what 'special' means
  - Automatic designation of region if meets requirements
  - What precision can we justify on x,y,z?

- User-proposed approach (eg. EU: Sites of Special Scientific Interest; Landing site workshops)
  - Community / science team argue their case
  - As is being done now but teams will have tool at their disposal

Content source: Vicky Hipkin, Canadian Space Agency

Building a GIS

1. Define the goals
2. Assemble equipment and facilities
3. Train the personnel
4. Locate existing digital data / hardcopy data
5. Design methods and database
6. Data - do the work
    6.1. Data creation
    6.2. Data conversion
    6.3. Data updates
7. Analyze

70 - 80% cost of entire project

Content source: Trent Hare, USGS

Global Spatial Information Infrastructure - Review

Mars geodetic control network

RAND/USGS Mars Control Network 2003: improvement of the global Mars control network established earlier by RAND and USGS

- 1,054 Mariner 9 and 5,317 Viking Orbiter images.
- Constraining all 37,652 control points to radii from Mars Orbiter Laser Altimeter (MOLA) data and adding 1,232 "ground control points" whose horizontal coordinates are also constrained by MOLA.
- The RMS error of the geodetic/photogrammetric solution is 15.8 m (~1.3 Viking pixels, ~280 m on the ground).
- The IAU/IAG 2000 coordinate system is used for the network and the mosaic.
- It is primarily used in production of MDIM 2.1.

New orbital and ground data for verification and improvement needed!

Content source: Ron Li, Ohio State Univ.

Process for the Planetary Community

- **Increasingly broad implementation of these specifications - and thus ability to share - is facilitated by:**
  - Obvious utility once implementations are in place (they are)
  - Minimal cost and effort to produce the simplest implementations
  - Substantial and growing availability of commercial and open-source implementations
- **Implementation of the Mars-Spatial web will probably reflect the same process that is occurring for terrestrial data**
  - Existing implementations of the broadest datasets will be widely accessed and referenced
  - Technology will be spread as people discover interoperability features offered by the systems they are already using, or can easily acquire
- **How to abet this natural diffusion?**
  - Publicize and promote existing successes
  - Leverage wide availability of commercial and open-source client software - web-based tutorials, pointers to resources, examples
  - GDAL support for PDS

Content source: Philip Dibner, Ecosystem Assoc.